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SOIL CONSERVATION SERVICE

DEPENDABILITY OF SURFACE RUNOFF SUPPLIES IN THE RIDGES AND VALLEYS REGION OF VIRGINIA

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In cooperation with the
Virginia Agricultural Experiment Station

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SCS-TP-113
Washington 25, D. C.
April 1953

292555

DEPENDABILITY OF SURFACE RUNOFF SUPPLIES IN THE RIDGES AND VALLEYS REGION OF VIRGINIA[1]

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INTRODUCTION

Our progressing agriculture is demanding water for crop and livestock production in continually greater amounts. Grassland farming, farm home modernization, supplemental irrigation, orchard spraying, and other farm activities require supplies which will be adequate for either regular withdrawals, such as drinking water for stock, or for special withdrawals at irregular intervals as for supplemental irrigation. Many farms do not have springs or streams and must depend on storage of surface runoff for these uses.

This paper deals with the dependability of surface runoff water in the replenishment of farm ponds for various use requirements. It describes a method of estimating the minimum amount of runoff water that can be expected during various periods under specified cropping conditions on certain typical soils, such as Dunmore, Groseclose, and Westmoreland, in the Ridges and Valleys of Virginia. By planning water usage within the limits of replenishment from the least amount of runoff to be expected, a reasonable degree of assurance of success can be attained.

PRESENTATION OF DATA

Basic data used in determining dependability of water supplies are given in tables 1 and 2.

Table 1 presents estimates of average water requirements for certain household, crop, and livestock purposes. The daily values were obtained from the Virginia Agricultural Workers Handbook[2] and the yearly amounts were computed from these values (or estimated as noted in the table) for direct use in later application.

The runoff-expectancy data presented in table 2 are applicable on Dunmore and other related soils of the Ridges and Valleys of Virginia. In this area, underlying limestone has a pronounced effect on the total amount of runoff. The data are based on runoff records of only 7 to 10 years' duration and can be considered as only tentative. The values presented in the table, however, are believed to be reasonable estimates of the minimum runoff in acre-feet per acre of watershed that can be expected for 1, 2, 3, and 4 consecutive-year periods under various cropping conditions.

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[1] Joint contribution of Soil Conservation Service, U. S. Department of Agriculture, and the Agricultural Engineering Department, Virginia Agricultural Experiment Station.

[2] Agricultural Extension Service. Agricultural Workers Handbook. Va. Polytechnic Inst., Blacksburg, Va. January 1950.

TABLE 1.--Farm and home water requirements

Item	Average quantity required		
	Gals. per day	*Acre-feet per year*	*Gals. per application*
Each member of family, all purposes	35	.039	
Each horse	10	.011	
Each steer or dry cow	12	.013	
Each cow producing milk	25-30	.034	
Each hog	2	.002	
Each sheep	1 1/2	.002	
Each 100 chickens	4	.004	
Orchard spraying[1]			
Apples trees, per year of age			1.0
Peach trees, per year of age			1.0
Irrigation[1]		1.0	

[1] Approximate estimates.

TABLE 2.--Minimum runoff, in acre-feet per acre of watershed, to be expected for consecutive periods under various cropping conditions

Watershed cropping condition	Minimum runoff expectancy for length of period			
	1 yr.	2 yr.	3 yr.	4 yr.
	Acre-feet per acre	*Acre-feet per acre*	*Acre-feet per acre*	*Acre-feet per acre*
A.[1] Pasture (natural bluegrass)				
1. Fertilized, moderately heavy grazed, 13% slope	0.00417	0.03917	0.06500	0.17750
2. Untreated, 13% slope	.00250	.02000	.04167	.13417
3. Fertilized, extremely heavy grazed, 23% slope	.03417	.07000	.20083	.43083
4. Poor, weedy, 23% slope	.03583	.08917	.22833	.46250
B.[2] Corn, wheat, clover rotation				
1. Contour strip cropped	.00167	.01000	.03000	.06000
2. Single crop each year	0	.00250	.08917	.20417
3. 1/3 of watershed in each crop but not contour strip-cropped	.00667	.04333	.18000	.31667

[1] TVA-Va. Agr. Expt. Sta. watersheds. From annual reports 1937-1943.
[2] VA. Agr. Expt. Sta.--SCS watersheds, Blacksburg, Va.

Table 2 shows that the runoff for a single year may be extremely low. Untreated pasture on 13-percent slope, for example, gave only 0.00250 acre-foot of runoff per acre for 1 year. However, the probability of this low value occurring for two consecutive years is slight. In this case, the lowest amount on record for two consecutive years was 0.02000 acre-foot per acre. The 2-year average of 0.01000 is considerably more than twice the 1-year low. Similarly, the 3-year average of 0.01389 acre-foot per acre per year is higher than the 2-year average. It is evident that if pond capacity exceeds the 1-year minimum the effect of a single year's deficiency will be minimized. As the pond capacity is increased, more years of runoff can be held with the result that the average annual yield is increased.

In solving a problem on the utilization of surface runoff, the objective is to achieve a balance between the dependable supply and the stipulated demand. The period of years necessary to produce this balance is the dependability period or design period. For example, if a 3-year average runoff is required to balance the stipulated demand, the pond should be designed with capacity to hold the total minimum runoff for the 3 years.

A formula which may be used for determining the balance between supply and demand is:

$Q\ A = N\ W$

in which Q = Minimum runoff for N years in acre-feet per acre
A = Area of watershed in acres
N = Period of consecutive years required to obtain dependable supply
W = Quantity of water needed in acre-feet per year.

No allowance is made in this formula for evaporation from the pond surface, since annual evaporation in this area is approximately equal to the annual amount of rain that would fall on the pond surface.

In the limestone areas of Virginia, where seepage may be a serious problem, suitable allowance must be made for water losses in making dependability estimates. Runoff dependability requires that seepage be at a minimum so that the maximum amount of water will be available for the desired purpose. Laboratory experiments at Blacksburg, Va., have demonstrated that seepage can be minimized by compacting the pond bottom at optimum moisture content.[3, 4] If seepage cannot be eliminated, the estimated water loss must be added to the stipulated demand in determining the aggregate dependable supply needed.

APPLICATION TO STOCK PONDS

Stock ponds considered herein are assumed to have a minimum average depth of 3 feet and a maximum watershed size of 50 acres.

The application of dependability-of-supply data (table 2) to stock ponds is illustrated in the following example.

A farmer with 30 dairy cows wants to construct a stock-water pond. The ideal location for the pond has a 47-acre watershed in fertilized, moderately heavy grazed pasture with an average slope of 13 percent.

The annual amount of water needed per cow is 0.034 acre-foot per year (table 1), or 1.02 acre-feet per year for 30 cows. The problem, therefore, is to determine the number of years of runoff required to supply an average of 1.02 acre-feet of runoff per year.

All of the dependability estimates will be taken from the data for the cropping condition listed in table 2 which is most similar to the one in the hypothetical watershed, in this instance item A-1.

The most desirable dependability period is determined by solving the equation $QA = NW$ for various dependability periods, using for each specific period selected the minimum expected runoff values shown in table 2. The solution which gives a balanced equation is found by trial.

Thus, a trial solution for 2-year dependability is obtained as follows:

Given: Q = 0.03917 acre-foot per acre (from table 2)
A = 47 acres
N = 2 years
W = 1.02 acre-feet per year

By substituting in the formula, we obtain

$$0.03917 \times 47 = 2 \times 1.02$$
$$1.84 = 2.04$$

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[3] Holtan, H. N. Sealing Farm Ponds. Agr. Engin. 31:125-130, 133-134, illus., 1950.

[4] Holtan, H. N. Holding Water in Farm Ponds. U. S. Soil Conserv. Serv. SCS-TP-93. 10 pp., illus., July 1950.

A 2-year period evidently would not provide a dependable supply since the calculated supply of 1.84 acre-feet is 0.20 acre-foot short of meeting the 2-year demand of 2.04 acre-feet. Therefore, a second trial solution is made, basing the calculations on a 4-year dependability period:

Given: $Q = 0.17750$
$A = 47$
$N = 4$
$W = 1.02$

By substituting in the formula, we obtain

$$0.17750 \times 47 = 4 \times 1.02$$
$$8.34 = 4.08$$

The 4-year dependability, therefore, would produce an excess of 4.26 acre-feet per 4 years.

Evidently the satisfactory dependability period lies somewhere between the 2-year and 4-year periods. The calculation for the 3-year dependability period follows:

Given: $Q = 0.06500$
$A = 47$
$N = 3$
$W = 1.02$

By substituting in the formula, we obtain

$$0.06500 \times 47 = 3 \times 1.02$$
$$3.06 = 3.06$$

The 3-year dependability period gives a balance between dependable supply and stipulated demand; therefore, the pond would be constructed to hold a 3-year supply; i.e., 3.06 acre-feet. Actually, in a pond of this size, the stipulated annual consumption would never completely empty the pond since minimum runoff could be counted on to replenish the accumulated usage before 3 years had passed.

If herd expansion is contemplated, it would be desirable to design the pond with a 4-year capacity (8.34 acre-feet per 4 years). This would provide 2.085 acre-feet of water per year. The number of livestock that could be supplied is obtained by dividing the annual available water supply by the annual requirement (table 1). Thus, for dairy cows, the 4-year-capacity pond would supply sufficient water for 2.085/0.034, or 61 cows.

APPLICATION TO IRRIGATION PONDS

An irrigation pond must have a dependable supply if it is to provide assurance against crop failure. Supplemental irrigation is most needed in a dry year since runoff is then liable to be small. Irrigation ponds, therefore, should be designed to hold a sufficient amount to provide several years usage. By combining the runoffs of several years, the effect of any low runoff year is minimized.

The following example illustrates the application of dependability-of-supply data (table 2) to irrigation ponds.

The problem is to determine the amount of water that can be withdrawn annually from a 4-acre pond having a 32-acre-foot capacity and a 100-acre watershed, with assurance of replenishment from the contributing watershed. The watershed consists of 75 acres of fertilized, extremely heavy grazed pasture with an average slope of 23 percent, and 25 acres of corn, wheat, and clover in rotation planted in contour strips.

The amount of water that can be withdrawn annually from the pond with assurance of replenishment is determined by finding the number of years required to supply 32 acre-feet of runoff from the watershed.

The dependable supply will be equal to QA for pasture (item A-3, table 2) plus QA for contour strip cropping (item B-1, table 2). With a stipulated demand of 32 acre-feet, the formula would be:

$$QA \text{ (pasture)} + QA \text{ (contour strip cropping)} = 32$$

Solving for 2-year dependability gives:

$$(0.07000 \times 75) + (0.01000 \times 25) = 32$$
$$5.50 = 32$$

This solution fails to provide a balance in the terms of the formula. The wide discrepancy in the two figures of the end equation indicates the probability of a deficit of 26.50 acre-feet if 32 acre-feet should be withdrawn in 2 years.

Solving for 3-year dependability gives:

$$(0.20083 \times 75) + (0.03000 \times 25) = 32$$
$$15.81 = 32$$

A deficit of 16.19 acre-feet could probably occur in 3 years if 32 acre-feet should be withdrawn in the 3-year period.

Solving for 4-year dependability gives:

$$(0.43083 \times 75) + (0.06000 \times 25) = 32$$
$$33.81 = 32$$

The 4-year period, therefore, would assure replacement of the 32-acre-feet withdrawal. This would allow an average annual withdrawal of 32/4 or 8 acre-feet.

Increased water yields to supply mounting needs are usually obtained by storing runoff from larger watersheds. These larger watersheds emphasize the need for careful design of spillways which will accommodate greater peak flows. A basis for estimating peak-rate expectancies has been presented in a previous publication.[5] Other methods such as the modified Cook method[6] and the recently developed method suggested by Holtan and Kirkpatrick[7,8] may also be used in estimating peak flows.

SUMMARY

When surface runoff is the source of water for pond supply, the dependability of recurrence of needed amounts to refill the pond at desired frequencies must be estimated. As a basis for such estimates, runoff records were analyzed to find the least amount of runoff occurring in any single year, any two consecutive years, three consecutive years, and four consecutive years. Records were available for various cropping conditions on Dunmore and related soils typical of the limestone areas of Virginia.

Water usage within the limits of replenishment can be designed with reasonable accuracy through calculations based on the least amount of runoff to be expected.

If the pond is large enough to hold several consecutive years of runoff, the average annual replenishment is greater; consequently, permissible annual withdrawal is increased. Annual withdrawal can be balanced against average annual replenishment through application of the formula: $QA = NW$.

The area of the watershed should be carefully considered in designing the pond spillway. In many instances larger watersheds are needed to meet the demands for water. Increased danger of overtopping of dams due to larger peak flows, together with the increased value of the entire structure to the farm operation, makes the proper design of spillways especially important.

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[5] Edminister, T. W. and Lillard J. H. Rates of Runoff in the Ridges and Valleys of Virginia. U. S. Soil Conserv. Serv. SCS-TP-67. May 1948.

[6] U. S. Soil Conser. Serv. Procedure for Determining Peak Flow, Total Volume of Runoff, Hydrograph Development, and Flood Routing. [A modification of a procedure presented by H. L. Cook in Farmers' Bulletin No. 1859 entitled Stock Water Developments--Wells, Springs and Ponds]. Adaptation released by Water Conservation Division of Region II, SCS, Spartanburg, S. C.

[7] Holtan, H. N. and Kirkpatrick, M. H. Rainfall, Infiltration and Hydraulics of Flow in Runoff Computation. Amer. Geophys. Union Trans. 31(5), Pt. I. 1950.

[8] Holtan, H. N. and Kirkpatrick, M. H. Suggested Method for Estimating Runoff (For consideration and testing)- In-Service Report. U. S. Soil Conserv. Serv. June, 1950.